King Saud University
College of Science
Physics & Astronomy Dept.

PHYS 111 (GENERAL PHYSICS 2)

CHAPTER 35: The Nature of Light and the principles of ray Optics

LECTURE NO. 7

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35.1 The Nature of Light

- Light was considered to be a stream of particles that either was emitted by the object being viewed or emanated from the eyes of the viewer.
- **Newton,** the chief architect of the particle model of light, held that particles were emitted from a light source and that these particles stimulated the sense of sight upon entering the eye. Using this idea, he was able to explain

reflection and refraction.

35.1 The Nature of Light

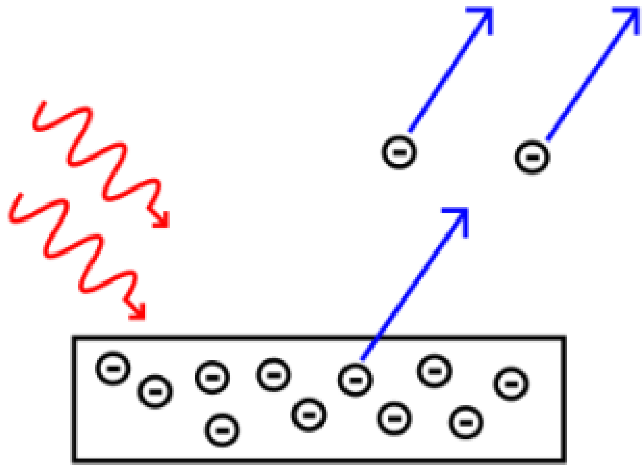
Is light a wave or a particle?

- In the early 19th century, the English scientist **Thomas Young** carried out the famous double-slit experiment which demonstrated that a beam of light, when split into two beams and then recombined, will show interference effects that can only be explained by assuming that light is **a wavelike disturbance.**

- By 1820, **Augustin Fresnel** had put this theory on a sound mathematical basis, but the exact nature of the waves remained unclear until the 1860's when James Clerk Maxwell developed his **electromagnetic theory.**

35.1 The Nature of Light

- However, **Einstein**'s 1905 explanation of the photoelectric effect (The photoelectric effect is the observation that many metals emit electrons when light shines upon them. Electrons emitted in this manner may be called photoelectrons.) showed that light also exhibits **a particle-like nature**. The photon is the smallest possible packet (quantum) of light; it has zero mass but a definite energy

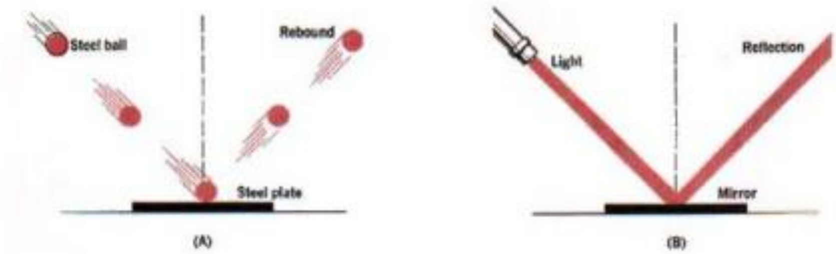


Photoelectric effect

35.1 The Nature of Light

Wave Theory of Light

- **Newton** proposed that light consists of a stream of small **particle**s, because it
  - travels in straight lines at great speeds
  - is reflected from mirrors in a predictable way



- Thomas **Young** showed that light is a **wave**, because it
  - undergoes diffraction and interference

35.1 The Nature of Light

Wave Theory of Light

- An explanation of the photoelectric effect was proposed

by Einstein in 1905 in a theory that used the concept of quantization developed by Max Planck (1858–1947) in 1900.

- The quantization model assumes that the energy of alight wave is present in particles called **photons**; hence, the energy is said to be quantized.
- Photon is the smallest part of light.
- According to Einstein's theory, the energy of a photon is proportional to the frequency of the electromagnetic wave: $E = hf \quad , h\ is\ the\ Planck's\ constant = 6.63 \times 10^{-34} J\ .s$

35.1 The Nature of Light

Is light a wave or a particle?

In view of these developments, light must be regarded as having a dual nature:

Light exhibits the characteristics of **a wave** in some situations and the characteristics of **a particle** in other situations.

35.2 Measurements of the Speed of Light

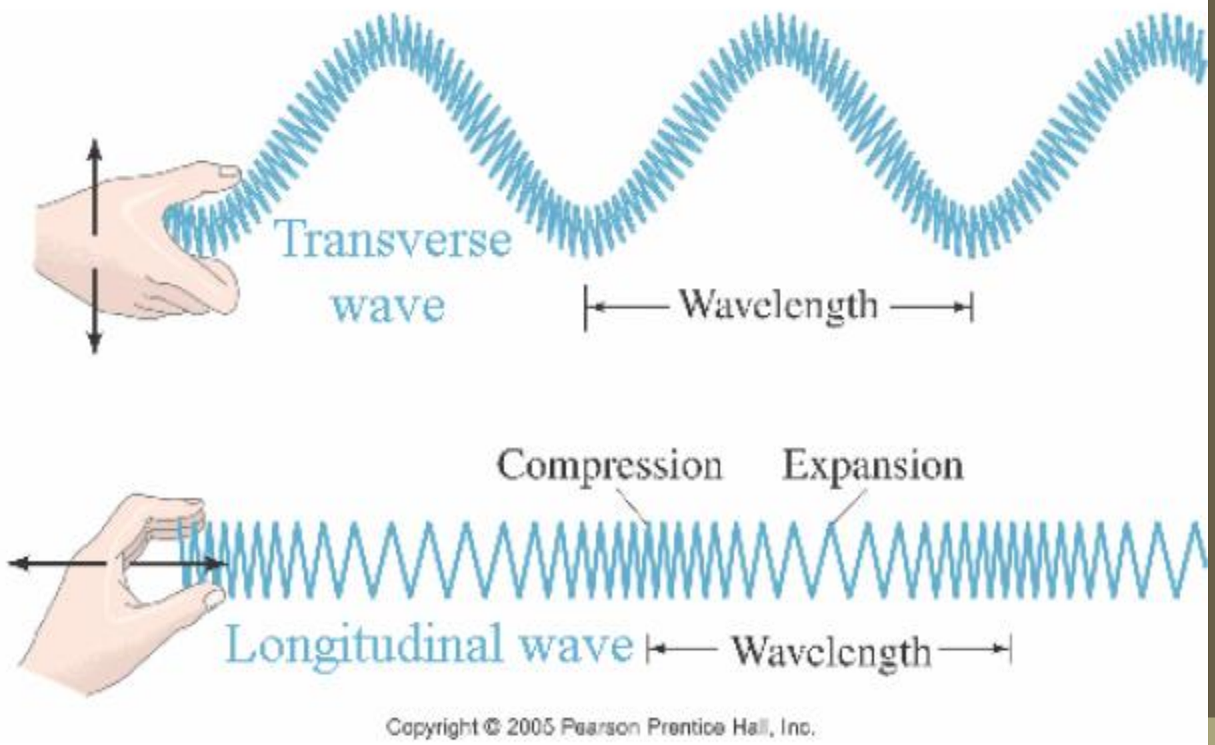
– Until around 1700, it was still debated whether the speed of light was infinite (traveled instantaneously from point to point)

– In 1676, Olaus Romer used the eclipses of Jupiter's moons to establish the finite speed of light and make a rough measurement

$$c = 3.00 \times 10^8 \text{ m/s} = 186{,}000 \text{ mi/s}$$

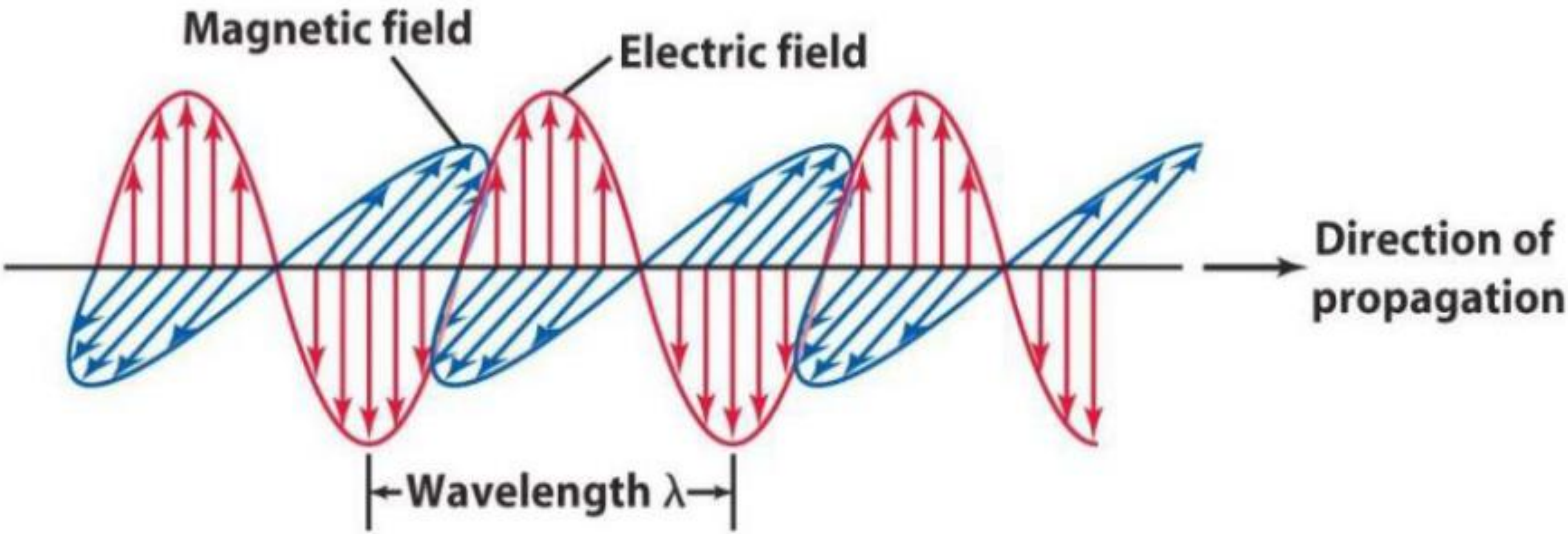
Type of Wave

- **Transverse wave** - movement or displacement is perpendicular to the direction of the wave. i.e light wave.
- **Longitudinal wave** - movement or displacement is parallel to the direction of the wave. i.e sound wave.

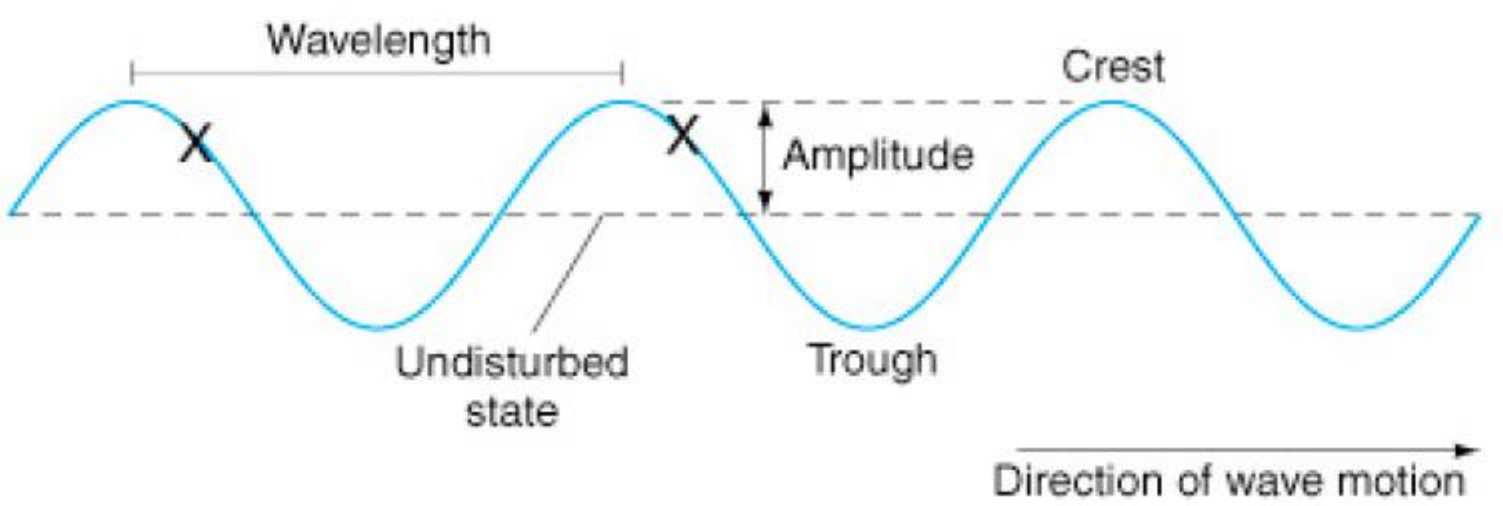


Wave Nature of Light

- In the case of light, waves are carried by electromagnetic fields
- Light = Electromagnetic Radiation



Properties of Light



Properties of Light

- Crest and trough
- **Amplitude** - maximum excursion from its undisturbed or relaxed position.
- Waves travel at a **speed**, V.
- The number of crests that pass at a specific point in space is called a wave's **frequency f or ν** , and is recorded in units of Hertz.
- **Period τ** - the time it takes for one complete cycle, measured in seconds. This is known as **τ**.
- **Wavelength** λ- the distance a wave travels during one complete oscillation.

$$\mathbf{f = 1/\tau}$$

$$\mathbf{(\lambda) = V\tau \text{ or } V/f}$$

Properties of Light

- Wavelength & speed of light are related by the frequency

f - frequency of light (Hz)

c - speed of light

λ - wavelength of light

- This is actually true for any wave $\nu = c/\lambda$

ν - frequency of wave

c - speed of wave

λ - wavelength

Energy of a Photon

- A photon is characterized by either a wavelength, denoted by λ or equivalently an energy, denoted by E. There is an inverse relationship between the energy of a photon (E) and the wavelength of the light (λ) given by the equation:

$$E = hc/\lambda$$

- where h is Planck's constant and c is the speed of light.

$$h = 6.626 \times 10^{-34}\ \mathrm{J}$$

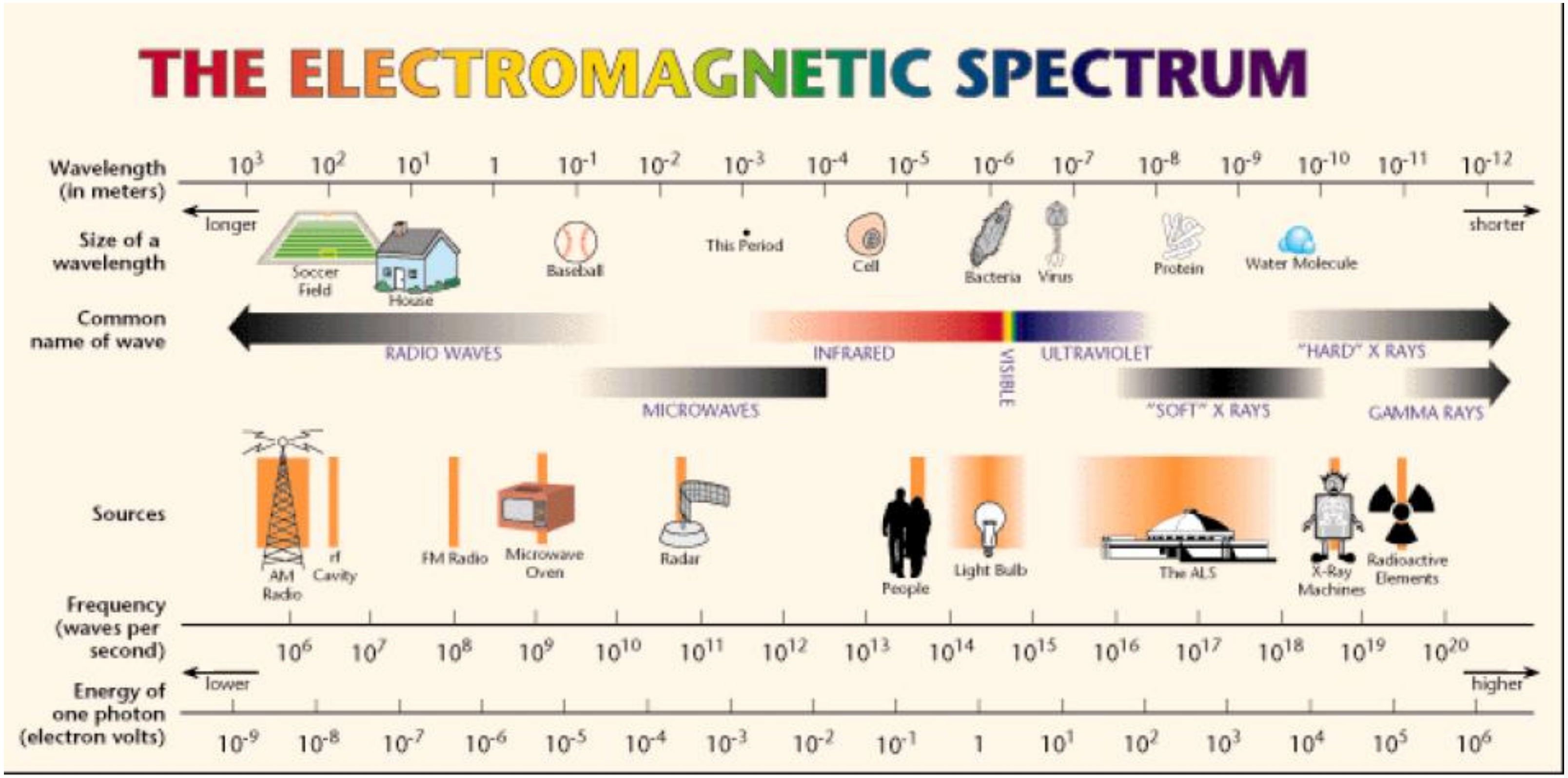
$$c = 2.998 \times 10^{8}\ \mathrm{m/s}$$

Energy of a Photon

- By multiplying h and c to get a single expression, $hc = 1.99 \times 10^{-25}$ joules-m.

- The $E = hc/\lambda$ inverse relationship means that light consisting of high energy photons (such as "blue" light) has a short wavelength. Light consisting of low energy photons (such as "red" light) has a long wavelength

Electromagnetic Spectrum



Electromagnetic Spectrum

- The electromagnetic (EM) spectrum is the range of all types of EM radiation.
- Radiation is energy that travels and spreads out as it goes – the visible light that comes from a lamp in your house and the radio waves that come from a radio station are two types of electromagnetic radiation.
- The other types of EM radiation that make up the electromagnetic spectrum are microwaves, infrared light, ultraviolet light, X-rays and gamma-rays.

Electromagnetic Spectrum

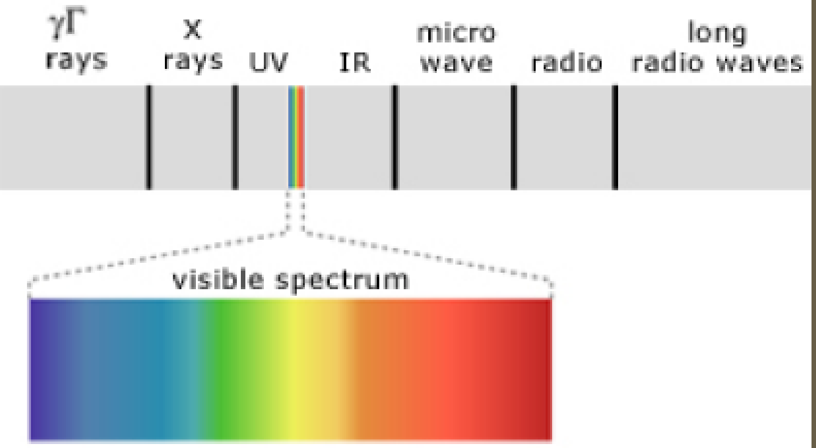
- **Radio**: Your radio captures radio waves emitted by radio stations, bringing your favorite tunes. Radio waves are also emitted by stars and gases in space.
- **Microwave**: Microwave radiation will cook your popcorn in just a few minutes, but is also used by astronomers to learn about the structure of nearby galaxies.
- **Infrared**: Night vision goggles pick up the infrared light emitted by our skin and objects with heat. In space, infrared light helps us map the dust between stars.

Electromagnetic Spectrum

- **Visible**: Our eyes detect visible light.light bulbs, and stars all emit visible light.
- **Ultraviolet**: Ultraviolet radiation is emitted by the Sun and are the reason skin tans and burns. "Hot" objects in space emit UV radiation as well.
- **X-ray**: A dentist uses X-rays to image your teeth, and airport security uses them to see through your bag. Hot gases in the Universe also emit X-rays.
- **Gamma ray**: Doctors use gamma-ray imaging to see inside your body (medical applications)

Color of light

- As seen in the figure, light at one end of the visible spectrum has shorter wavelengths near the 400nm range of the spectrum producing a "blue" visual sensation.
- Medium wavelengths in the 500-600nm range produce a "yellow to green" sensation. Longer wavelengths produce a "reddish" sensation.
- Primaries color: Red (R), Green (G), Blue (B)



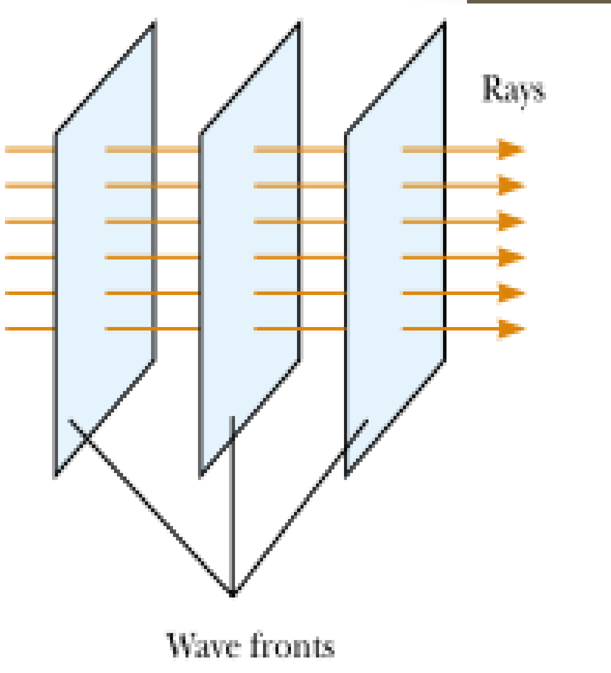
35.3 The Ray Approximation in Geometric Optics

- The field of **geometric optics** involves the study of the propagation of light, with the assumption that light travels in a fixed direction in a straight line as it passes through a uniform medium and changes its direction when it meets the surface of a different medium .

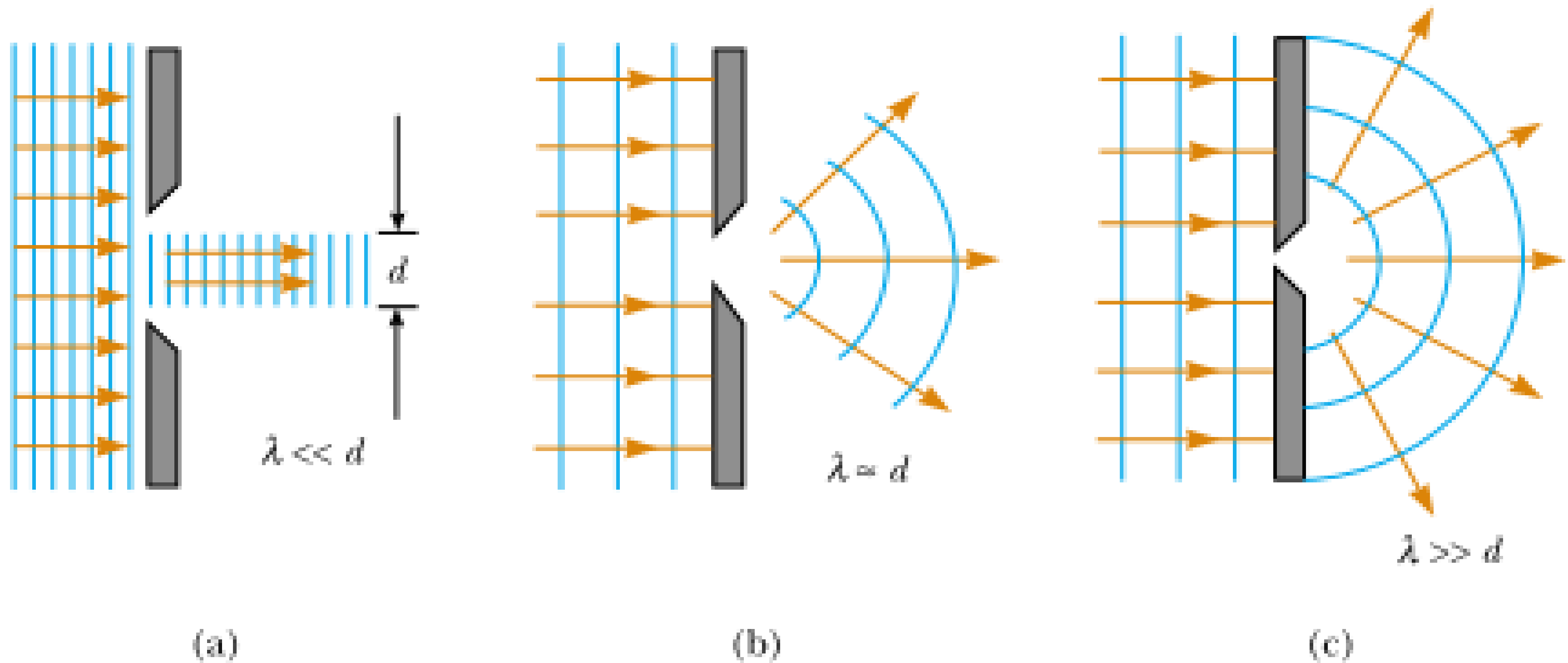
- we use what is called **the ray approximation**.
- In the ray approximation, we assume that

a wave moving through a medium travels in

a straight line in the direction of its rays.



35.3 The Ray Approximation in Geometric Optics



Active Figure 35.4 A plane wave of wavelength λ is incident on a barrier in which there is an opening of diameter d. (a) When $\lambda \ll d$, the rays continue in a straight-line path, and the ray approximation remains valid. (b) When $\lambda \approx d$, the rays spread out after passing through the opening. (c) When $\lambda \gg d$, the opening behaves as a point source emitting spherical waves.

Summary

- The Nature of Light
- Is light a wave or a particle
- Measurements of the Speed of Light
- Wave Nature of Light
- Properties of Light
- Energy of a Photon
- Electromagnetic Spectrum
- The Ray Approximation in Geometric Optics

The End